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MEDICINE

Evaluating Colored VR Navigation for Laminectomy and Mastoidectomy

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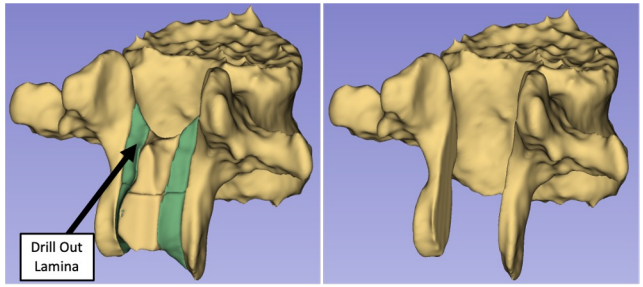
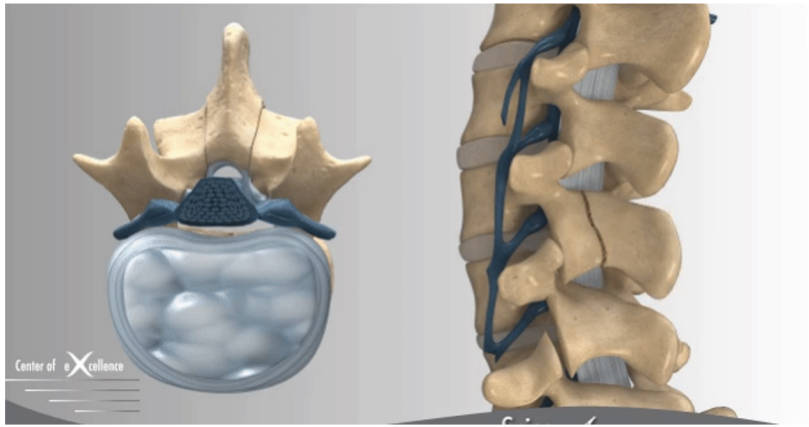
Mentors: David Usevitch, Hisashi Ishida, Adnan Munawar

Background: Laminectomy

- Procedure that **removes portions of the lamina**, a vertebral bone that forms the posterior of the spinal canal covering the spinal cord
- Treat spinal stenosis
- 500,000 cases annually, **11%** result in incidental durotomy [1]

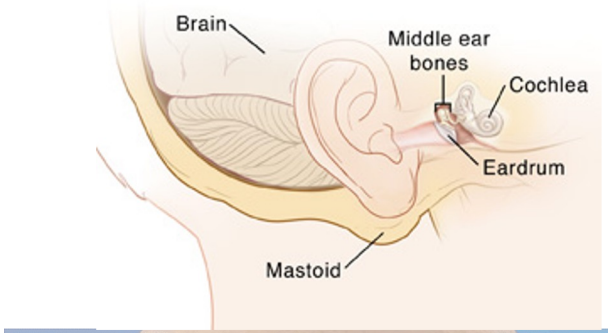




[1] K. Phan, R. J. Mobbs, Minimally Invasive Versus Open Laminectomy for Lumbar Stenosis: A Systematic Review and Meta-Analysis, Spine 41 (2) (2016) E91–E100. doi:10.1097/BRS.0000000000001161

Background: Mastoidectomy

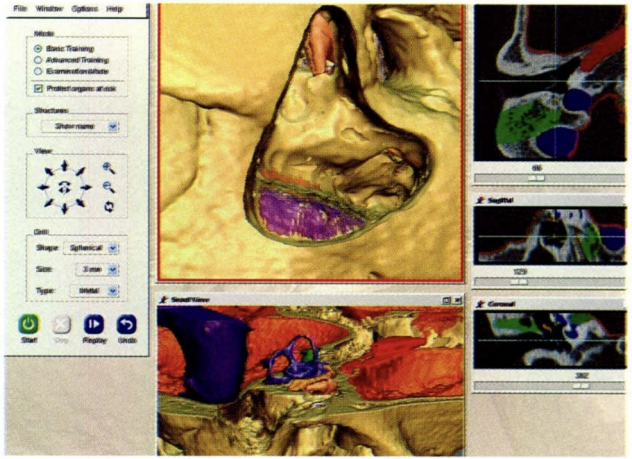
- Procedure drills into parts of the **temporal bone** to reach the internal auditory canal
- Vital structures are exposed
- 60,000 cases annually, **cognitive load** for surgeons can peak at around 10% [2]



[2] S. A. W. Andersen, P. T. Mikkelsen, L. Konge, P. Cayé-Thomasen, M. S. Sørensen, Cognitive load in distributed and massed practice in virtual reality mastoidectomy simulation, The Laryngoscope 126 (2) (2016) E74–79. doi:10.1002/lary.25449

Why Virtual-Reality?

- There exists a need to **better train surgeons**
- VR simulators provide low-stress **practice environments**
- Demonstrated **reduced complications** and **shorter operation times** [3]



[4]

[3] A. Hussain, A. Malik, M. U. Halim, A. M. Ali, The use of robotics in surgery: a review, International Journal of Clinical Practice 68 (11) (2014) 1376–1382. doi:10.1111/ijcp.12492

[4] Rudolf Leuwer, Andreas Petersik, Bernhard Pflesser, Andreas Pommert, Boris Tolsdorff, Karl Heinz Höhne, Ulf Tiede: VOXEL-MAN TempoSurg: A Virtual Reality Temporal Bone Surgery Simulator. Journal of Japan Society for Head and Neck Surgery 17 (3), 2007, 203-207

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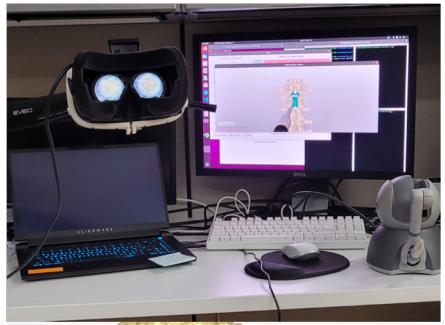
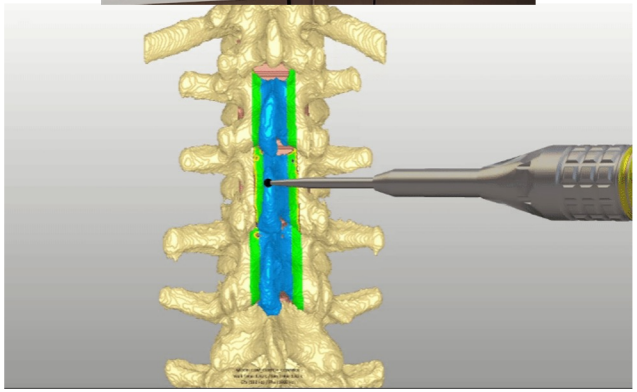
Prior Work

- **Colored VR navigation** using sine-distance functions (SDF)
- Uses **AMBF** platform as backbone [5]
- Upload **segmented CTs to GUI**





[5] A. Munawar, Z. Li, P. Kunjam, N. Nagururu, A. S. Ding, P. Kazanzides, T. Looi, F. X. Creighton, R. H. Taylor, M. Unberath, Virtual Reality for Synergistic Surgical Training and Data Generation, Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization 10 (4) (2022) 366–374, arXiv:2111.08097 [cs]. doi:10.1080/21681163.2021.1999331. URL http://arxiv.org/abs/2111.08097

Project Goals

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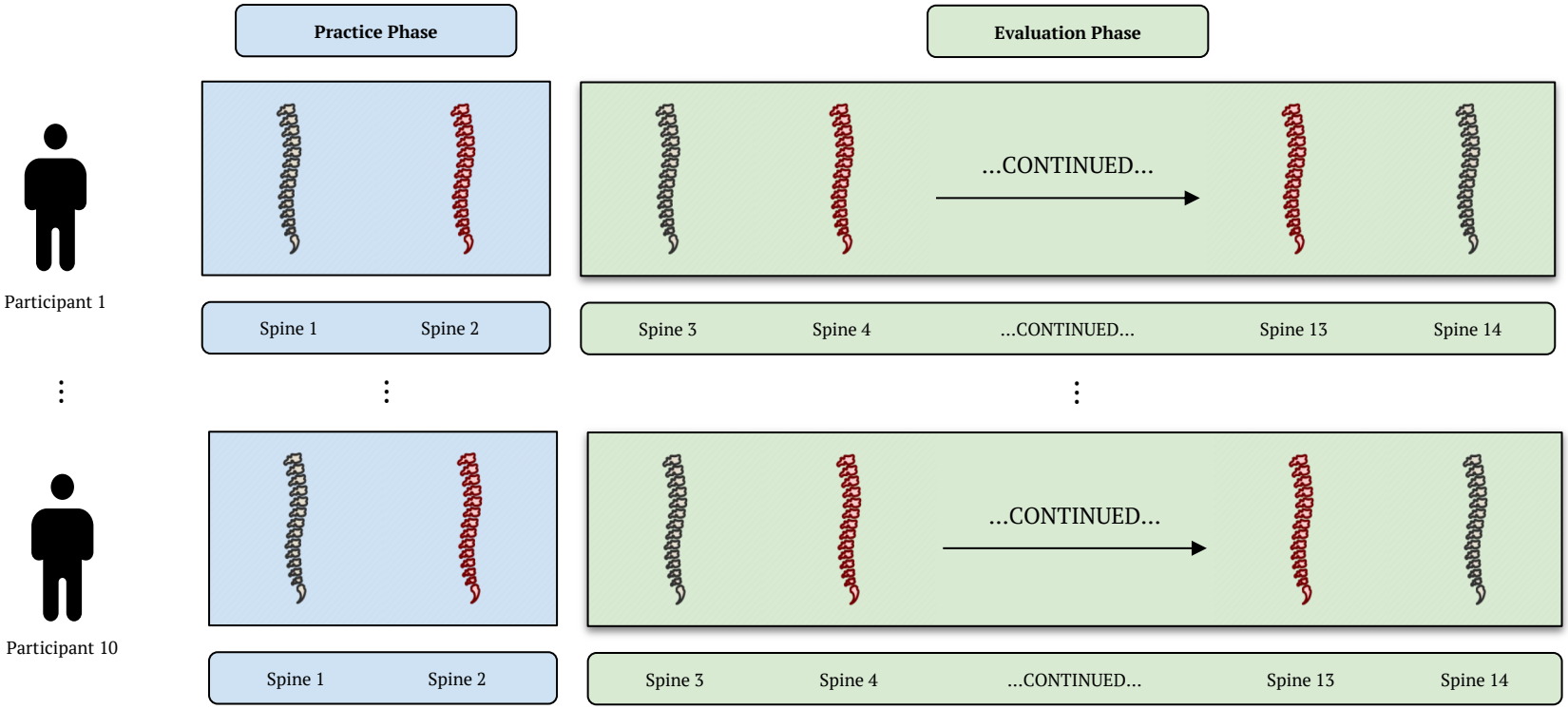
Evaluate the clinical utility of colored VR navigation for surgical tasks

1. Conduct a **comparative user study for laminectomy**
2. Conduct a **feasibility study for mastoidectomy**

Augment user experience for future user studies

1. Improve VR GUI including **depth perception** and synchronized data extraction

Laminectomy Study: Overview



Laminectomy Study: Logistics

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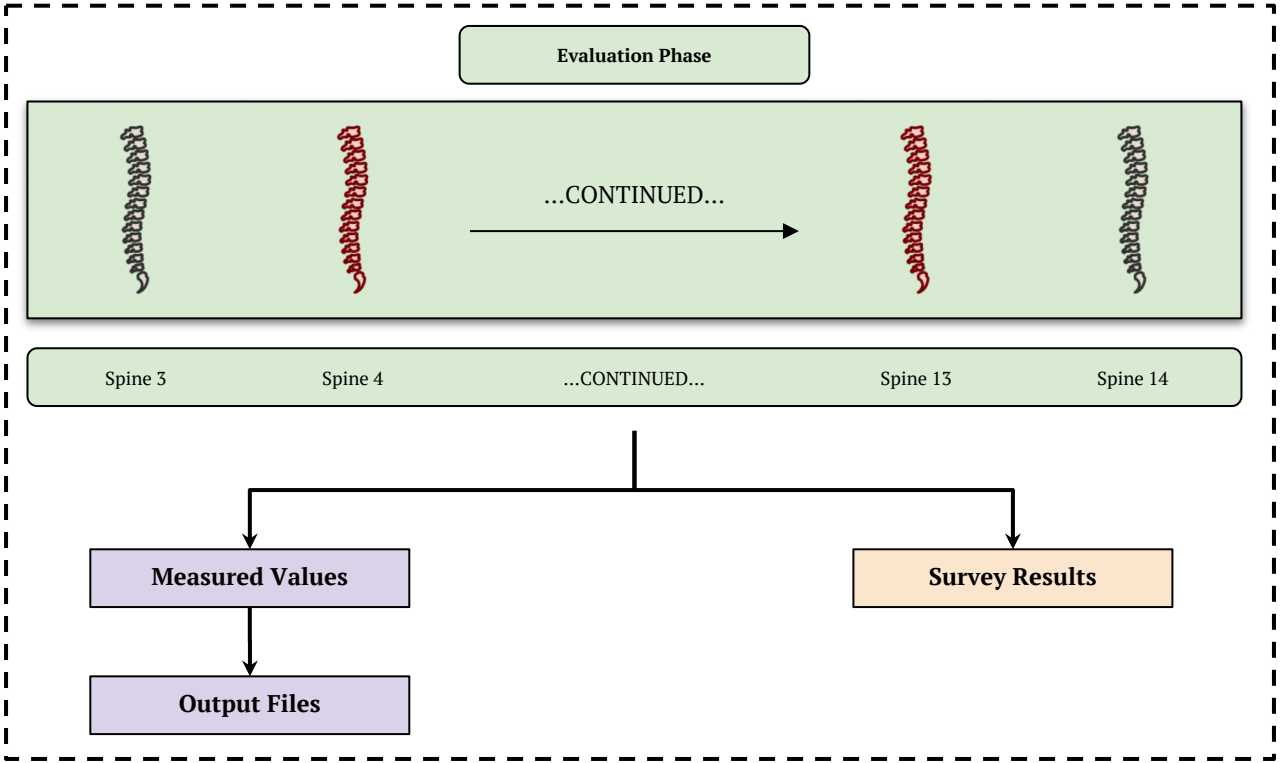
Recruitment	Schedule	Resources
• ≤10 subjects • JHH personnel • Leverage project mentors/LCSR contacts	• Mar-Apr 2023 • Thursday mornings at JHH • 1 hr/subject • Data collection monitored by a team member	• VR GUI + Phantom Omni • 15 lumbar spine cases • 5 mastoid cases • JHH badge access and study room

Laminectomy Study: Protocol



Laminectomy Study: Analysis

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Navigation Methods

- # voxels removed by color
- # breaches
- # warnings
- drilling time(s)/case
- mean thickness of remaining lamina

Survey Responses

- user performance metrics stratified by # years of surgical experience
  - ≤1, 2, 3, ≥4
- qualitative analysis of interviews

Mastoidectomy Feasibility Study

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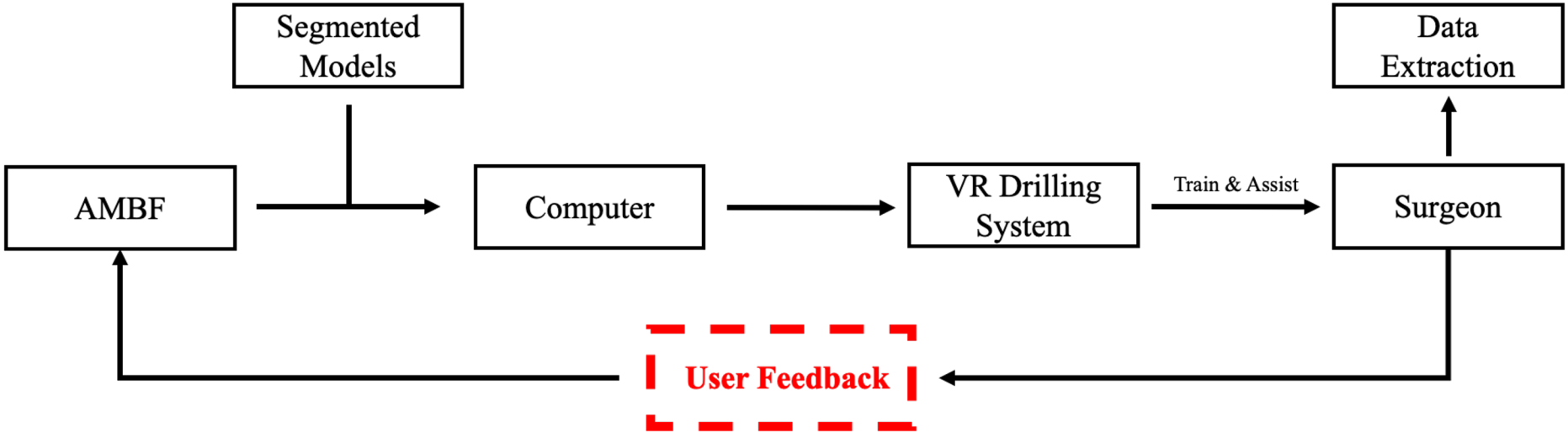
- **Smaller study**
  - 3-5 subjects performing 3-5 mastoidectomies
- **Not comparative**
  - Excluding A/B test against non-colored navigation
  - Comparison will be made against performance as reported in prior literature
- **Feasibility study**
  - Written for *Otology and Neurotology* as a feasibility study in the style of Razavi et al. [6]

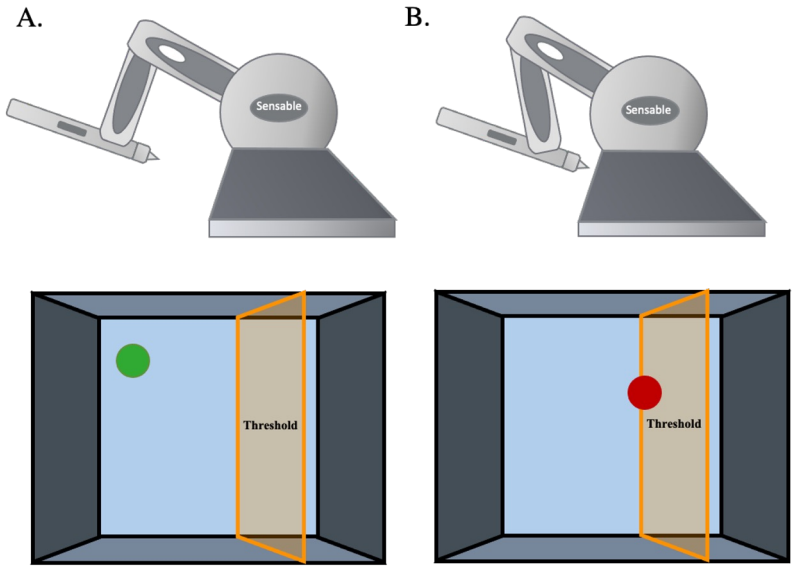
[6] Razavi CR, Wilkening PR, Yin R, Barber SR, Taylor RH, Carey JP, Creighton FX. Image-Guided Mastoidectomy with a Cooperatively Controlled ENT Microsurgery Robot. Otolaryngol Head Neck Surg. 2019 Nov;161(5):852-855. doi: 10.1177/0194599819861526. Epub 2019 Jul 23. PMID: 31331246.

Technical Approach



Depth Perception Interface

- Users could misinterpret hitting phantom base as haptic feedback from drilling anatomy
- Need to visualize physical workspace in GUI
- Establish frame of phantom using a calibration step



Deliverables: Minimum

Activities	Results
Familiarize **segmenting a lumbar spine CT scan** with 3D Slicer	A **reproducible protocol** for segmenting lumbar spine CTs using 3D Slicer software
Segmenting lumbar spine CTs following protocol	**15 locally-saved segmentation files** of lumbar spines
Build VR simulator and upload 15 lumbar spine segmentations to GUI	**Ready-to-use laptop with VR GUI** for laminectomy user study

Deliverables: Expected

Activities	Results
Conduct laminectomy user sessions at JHH	**Collect** user VR session **data**
Performing data analysis	**Written results section** for *IEEE* manuscript
Determine relevant anatomy to segment **for mastoidectomy** navigation	A **reproducible protocol** for segmenting inner ear CTs using 3D Slicer software
Segmenting inner ear CTs following protocol	**Collect** user VR session **data**
Implement a **depth perception interface**	**Mini-GUI** to visualize phantom workspace built into simulator
Upload inner ear segmentations to GUI	**Ready-to-use laptop with VR GUI** for mastoidectomy user study

Deliverables: Maximum

Activities	Results
Conduct mastoidectomy user sessions at JHH	**Collect** user VR session **data**
Performing data analysis	**Written results section** for *Otology and Neurotology* manuscript
Literature review and discussions with mentors and ENT surgeons	First-authored **manuscript** for *Otology and Neurotology*
Implement a C++ plugin for **synchronized data extraction**	**Unit-tested and documented program** for data extraction added into VR simulator

Milestones: Laminectomy Study

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Milestones	Exit Criteria
Spine CT segmentation	Five lumbar spines saved as **15 segmentation files of CT scans** of L1-L3
VR platform setup	VR platform with **GUI** containing spine cases
Finalize user study protocol for laminectomy user studies	Written and mentor-approved **protocol outlining data collection and analysis**
Schedule laminectomy user studies	**Confirmed sessions with up to 10 subjects** and planned monitoring assignments for team members
Collect surgeon data and perform data analysis	**Written results section** for *IEEE* manuscript

Milestones: Mastoidectomy Study

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Milestones	Exit Criteria
Inner ear CT segmentation	Five inner ears saved as **15 segmentation files of CT scans** of L1-L3
Incorporate new features into VR platform	VR **GUI** with depth perception interface
Schedule laminectomy user studies	**Confirmed sessions with up to 5 subjects** and planned monitoring assignments for team members
Collect surgeon data and perform data analysis	**Written results section** for *Otology and Neurotology* manuscript

Milestones: VR GUI Development

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Milestones	Exit Criteria
Depth perception interface	**Functional, unit-tested, and documented Python script** that builds a workspace model, captures the current phantom pose as input, and marks the relative position
Synchronized C++ data extraction	A **C++ plugin** that captures user pose and drilling progress from ROS and outputs extracted data metrics

Timeline

Phase	Task	February		March				April				May		
Laminectomy User Study	Spine CT segmentation													
	Colored virtual-reality platform setup													
	Finalize clinical study protocol													
	Schedule user studies													
	Collect surgeon data and perform data analysis													
	Write draft of results for laminectomy user study													
Mastoidectomy Feasibility Study	Inner-ear CT Segmentation													
	Colored virtual-reality platform setup													
	Finalize clinical study protocol													
	Schedule user studies													
	Collect surgeon data and perform data analysis													
	Write draft of mastoidectomy feasibility study													
Virtual-reality GUI Development	Depth perception + documentation													
	Improve GUI warning alerts													
	Data extraction plugin + documentation													
Final Presentation & Report														

Dependencies

Dependency	Need	Status	Contingency	Planned	Hard
Full IRB approval for user study at JHH	Organize and execute user study	Ongoing (planned review this week)	N/A	3/6	3/12
Study participants	Participate in clinical study	Ongoing	N/A	3/5	3/17
Github access	Locally build VR system	**Completed**	N/A	2/20	2/20
CT scans & prior segmentations for laminectomy	Segment anatomy according to ENT surgeon recommendations	**Completed**	N/A	2/20	2/20
3D Slicer	Make segmentations	**Completed**	N/A	2/20	2/20
Linux machine and VR glass	Locally running VR simulator for user studies	Ongoing	Use lab's equipment	3/6	3/12
Access to hospital	Collecting clinical study data	Not started	Follow David	3/6	3/12
Access to drafted manuscript and IRB documents for laminectomy study	Review prior user study protocols	**Completed**	N/A	2/20	2/20
Swipe access to LCSR PhD Office	Access to VR glasses	Ongoing	Have Yi enter the LCSR PhD Office	2/25	3/3

Team Structure

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- **Kesavan Venkatesh: Logistics Lead**
  - Organize and oversee user study sessions
  - Draft results reports
- **Jonathan Wang: Clinical Lead**
  - Organize CT segmentation protocols
  - Draft clinical background for mastoidectomy paper
- **Yi Wang: Coding Lead**
  - Software development on GUI

Management Plan

- **Mentor meetings**: Thursdays at 5:45pm, Hackerman
- **Student meetings**: Once/twice a week, Brody Learning Commons
- **Communications**: Teams, email

References

1. K. Phan, R. J. Mobbs, Minimally Invasive Versus Open Laminectomy for Lumbar Stenosis: A Systematic Review and Meta-Analysis, Spine 41 (2) (2016) E91–E100. doi:10.1097/BRS.0000000000001161
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